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TITLE: GEOCHEMICAL PROVENANCE OF ANOMALOUS METAL CONCENTRATIONS IN STREAM SEDIMENTS IN THE ASHTON 1:250,000 QUADRANGLE, IDAHO/MONTANA/WYOMING

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GEOCHEMICAL PROVENANCE OF ANOMALOUS METAL CONCENTRATIONS IN STREAM SEDIMENTS IN THE ASHTON 1:250,000 QUADRANGLE, IDAHO/MONTANA/WYOMING

by

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ABSTRACT

Stream-sediment samples from 1500 sites in the Ashton, Idaho/Montana/Wyoming 1:250,000 quadrangle were analyzed for 45 elements. Almost all samples containing anomalous concentrations (exceeding one standard deviation above the mean value of any element) were derived from drainage basins underlain by Quaternary rhyolite, Tertiary andesite or Precambrian gneiss and schist. Aluminum, barium, calcium, cobalt, iron, nickel, magnesium, scandium, sodium, strontium, and vanadium have an andesite provenance. Most anomalous manganese, europium, hafnium, and zirconium values were derived from Precambrian rocks. All other anomalous elemental concentrations are related to Quaternary rhyolite.

This study demonstrates that multielemental stream-sediment analyses can be used to infer the provenance of stream sediments. Such data are available for many parts of the country as a result of the National Uranium Resource Evaluation. This study suggests that stream-sediment samples collected in the Rocky Mountains can be used either as pathfinders or as direct indicators to select targets for mineral exploration for a host of metals.

Introduction

A geochemical stream-sediment survey for 45 elements was conducted by the Los Alamos National Laboratory in the Ashton 1:250,000 quadrangle in eastern Idaho, southwestern Montana, and northwestern Wyoming (Fig. 1). This study was undertaken as part of the nationwide Hydrogeochemical and Stream Sediment Reconnaissance (HSSR) Program, which was a major component of the U.S. Department of Energy's National Uranium Resource Evaluation (NURE).

A total of 1500 sediment samples was collected. These were obtained from 1433 stream channels, 52 springs, and 15 ponds. The samples from Montana were collected in August 1976, whereas those in Idaho and Wyoming were collected in the summer of 1978. All samples were collected at a nominal reconnaissance density of one sample location per 10 km^2. Standardized field, analytical, and data-base management procedures were used during both sampling programs.

All 67,500 analyses for elements in these samples (except for 3,000 As and Zr analyses) are tabulated in the Ashton quadrangle report (Shannon, 1980). These data plus the As and Zr data are also available on magnetic tape from GJOIS Project, UCC-ND Computer Applications Department, 4500 North Building, Oak Ridge National Laboratory, P.O. Box X, Oak Ridge, TN 37830. Additional HSSR data are available for small areas along the northern and eastern margins of Yellowstone National park in the Bozeman quadrangle (Bolivar, 1979; 1980a) and the Cody quadrangle (Bolivar, 1980b).

Field Procedures

Enough fine-grained, organic-rich, water-transported sediment to yield a composite sample of 25 g after processing (as indicated below) was taken from beneath the water level at three adjacent spots at each spring or stream location. The sediment was put into a new, clean, and originally sealed, rip-top polyethylene bag which was then properly double labeled for delivery to the contractor's drying facility. After drying at <100°C, each sample was sieved through a 100-mesh stainless steel sieve. The minus 100-mesh fraction was put into a prewashed, 25-ml polyethylene vial which was then appropriately double-labeled and sealed for shipment to Los Alamos. All field observations and measurements were recorded on field data forms which were included with the samples.

The field observations represented the best judgment of the field sampler at a location and included general descriptions of the local bedrock, sediment, water, vegetation, terrain, weather, and possible contaminants. Because these observations were subjective and made quickly in the field, they should be held subordinate to formally documented information such as that provided by published topographic or geologic maps.

Each contractor was supplied field maps with the desired sample types and general locations symbolically premarked at Los Alamos. The field maps were generally 1:24,000 or 1:62,500 USGS topographic maps. As each location was sampled, a unique sample location number, preprinted on transparent adhesive labels that was provided with each identically numbered field data form, was placed on top of the precisely marked point representing the sample site on the field map. When a desired sample as specified could not be obtained, an identical or alternate sample type was picked, and the new sample type and location were marked on the field map and properly labeled as above. The latitude and longitude of each location was then computed by the sampling contractor within 48 h of taking each sample. Every location was later checked at Los Alamos by digitizing the sample locations on each map and comparing them to those computed in the field. The latitudes and longitudes were corrected if the field-computed locations were displaced by more than 300 m from the locations marked on the field maps. A final visual check of sample locations was made by overlaying computer-produced location plots on the field maps used. The computer program for generating the Universal Transverse Mercator map projection overlays was described by Cheadle (1977).

Analytical Procedures

All sediment samples were analyzed for total uranium by delayed-neutron counting (DNC) (Minor et al., 1981). A split of each sample was transferred to a clean 4-ml rabbit, weighed, and its weight recorded along with the appropriate location number. These rabbits were then loaded into a 50-sample transfer clip. The reactor pneumatic-transfer system and background radiation levels were checked, and standards were run for calibration. The transfer clip was installed and the samples were cycled through the system. The uranium concentration was automatically measured, converted to ppm, and entered into the data base. The lower limit of detection of this method was 0.01 ppm uranium, far below the range of uranium concentrations in natural sediment samples. Above the 1 ppm level, the uranium values in sediment measured by DNC at Los Alamos had a one-sigma error of less than 4%. The specially designed delayed-neutron detectors, were described by Balestrini et al. (1976).

Immediately upon completion of the uranium analysis of sediment samples by DNC, the same 4-ml sediment splits were entered into the neutron-activation analysis (NAA) sequence. The concentrations of 33 additional elements were determined by this procedure. These elements were Al, As, Au, Ba, Ca, Ce. Cl, Co, Cr, Cs, Dy, Eu, Fe, Hf, K, La, Lu, Mg, Mn, Na, Rb, Sb, Sc, Sm, Sr, Ta, Tb, Th, Ti, V, Yb, Zn, and Zr. The full DNC/NAA timing sequence used at Los Alamos for each sediment sample was: 20-s irradiation, 10-s delay, 30-s DNC analysis, 20-min delay, 500-s γ-ray count for short-lived radionuclides, 96-s re-irradiation, 14-day delay, and finally a 1000-s γ-ray count for long-lived radionuclides. The γ-ray counting was done by lead-shielded Ge(Li) detectors; the 4096-channel γ-ray data were recorded and subsequently analyzed for each individual element by computer. The analytical data for each sample was automatically printed along with the associated statistical errors. The lower detection limits for the various elements as reflected by the "less than" values (denoted by a minus sign in front of a concentration) in the data listings were the values for the individual elements at which the statistical counting error approached 50%. Typical lower detection limits for the elements determineo by NAA were reported in Nunes and Weaver (1978); however, the actual detection limit for an element depended upon the composition of the sample, and this limit may have been higher or lower than the typical value. At concentration values one order of magnitude above the lower detection limits, the relative errors were generally less than 10%.

A computer-controlled, energy-dispersive x-ray fluorescence system was used to determine Ag, Bi, Cd, Cu, Nb, Ni, Pb, Sn, and W in sediments. The system consisted of an automatic 20-position sample changer, a lithium-drifted silicon detector, a pulsed molybdenum transmission-target x-ray tube, a multi-channel analyzer, and a minicomputer. The sediment samples were prepared for analysis by grinding 6 g of each minus 100-mesh sample to a minus 325-mesh powder. A computer program positioned the 6-g samples in the x-ray beam, unfolded overlapping peaks, determined peak intensities for each element, and calculated the ratio of the intensity of each peak to that of the molybdenum K_α Compton peak. Concentrations of each element were then calculated using equations obtained by analyzing prepared standards. Detection limits were: 5 ppm for Ag, Bi, Cd, and Pb; 10 ppm for Cu and Sn; 15 ppm for Ni and W; and 20 ppm for Nb. When an analysis resulted in an elemental concentration that was below the detection limit, a minus sign preceding the value of the detection limit for that element was inserted in the data listings. The relative standard deviation was 10%

or less at the 100-ppm level and 20% or less at the 20-ppm level. Details of the method and equipment used were described by Hansel and Martell (1977).

A 5-mg portion of the minus 325-mesh sample that had already been analyzed by x-ray fluorescence was mixed with 10 mg of a buffer consisting of one part graphite and one part SiO_2. The sample/buffer mixture was placed into a graphite electrode that was used as the anode of a dc arc having a short circuit current of 6A for 10 s, then 17A for 50 s. Photomultiplier tubes in a direct-reading spectrograph were used to measure the second order 313.0-nm line of Be, the first order 670.7- and 610.3-nm lines of Li, the background spectra near these lines, and the 327.6-nm line of V. The 670.7-nm Li line was used for Li concentrations up to 10 ppm and the 610.3-nm line of Li was used for concentrations above 10 ppm. The V line was used to correct the Be value when V is present. The signals from the photomultiplier tubes were read by a digital voltmeter and were processed by a desk-top calculator. The results were simultaneously printed on paper and written on cassette tape for later transmission to a computer data file. The elemental concentrations of Be and Li were determined from the spectra, based on the results of previously run calibration standards. The lower detection limit for both elements was 1 ppm. When an analysis resulted in an elemental concentration that was below the detection limit, a minus sign preceding the value of the detection limit for that element was inserted in the data listings. Precision at the lower detection limit was ≈50% for both elements and improved to ≈25% at one order of magnitude above the lower limit.

Geology

A detailed discussion of the geology of the Ashton 1:250,000 quadrangle is beyond the scope of this paper. A brief summary of the lithology of the quadrangle is generalized geologic maps by the U.S. Geological Survey (1972) and IntraSearch (1979).

The Precambrian basement comprises dolomite, gneiss, schist, tremolite marble, and quartzite.

All Paleozoic and Mesozoic rocks are sedimentary. Cambrian strata include limestone, shale, and sandstone. Dolomite is the dominant Ordovician and Devonian rock type, and limestone is the chief Mississippian rock type. Pennsylvanian rocks are principally sandstone and siltstone whereas Permian rocks are chiefly phosphatic shale and sandstone.

Triassic rocks consist of siltstone, shale, and sandstone. Jurassic strata include sandstone, shale, and limestone. Cretaceous rocks are predominantly sandstone and shale.

Almost all Tertiary rocks are volcanic. The chief exceptions are Paleocene sandstone and shale. Eocene rocks are chiefly andesite, basalt, trachyte and rhyodacite. Pliocene-Pleistocene volcanics comprise rhyolite flows and ash-flow tuffs. Pleistocene volcanics are comprised almost wholly of rhyolite flows and ash-flow tuffs plus local basalt. Pleistocene sediments are glacial deposits. Recent sediments include alluvium, fan and terrace deposits, landslides, and windblown sand. There are also local hot-spring and hydrothermal-explosion deposits.

Methodology

For each of the 45 elements, computer maps and tabulations were made showing the distribution of sites from which the elemental content of the sediment samples exceeded one (σ), two (2σ), or three (3σ) positive standard deviations above the arithmetic mean for that element. Values less than the detection limit or of zero were excluded from consideration.

Each individual element map of the 1° by 2° Ashton quadrangle (U.S. Geological Survey, 1972) was subdivided into 32 15-minute quadrangles numbered consecutively from the upper left corner as shown in Figure 2. The number of sample values for sites within each quadrangle between σ and 2σ, between 2σ and 3σ, and exceeding 3σ were counted separately and recorded. Each quadrangle was scored separately for each element by adding the number of values between σ and 2σ to twice the number of values between 2σ and 3σ and to thrice the number of values exceeding 3σ. Based on these scores, the four quadrangles containing the highest sums were taken to represent the peak geographic concentrations of sites in the Ashton quadrangle from which samples containing the most anomalous values of that element were obtained. Hence the one-eighth of the total area of the Ashton quadrangle, from which the largest number of anomalous values and the most strongly anomalous values for that element were reported, were identified as most likely to have a decipherable geologic relation to the provenance of the stream-sediment samples. This process was repeated, in turn, for each of the other 44 elements.

For each 15-minute quadrangle, the areas, which include clusters of samples containing anomalous values of one or more elements, were plotted on the Ashton topographic map as shown in Figure 2. The geology of these areas was noted by transferring information from the 1:250,000 geologic overlay (IntraSearch, 1979) included in the Ashton NURE report (Shannon, 1980). For areas within Yellowstone National Park, the 1:125,000 geologic map was used (U.S. Geological Survey, 1972). The resulting information was tabulated (see Appendix) to determine the association of anomalous values of each metal with specific rock types throughout the Ashton quadrangle. Each major rock type in the areas upstream from sites, from which samples having anomalous concentrations of various elements were obtained, was used to match such elements with the lithology of their probable derivation Some samples may be recycled from terrace or glacial deposits, which ultimately had their provenance in other rock types cited.

Conclusions

The following groups of elements have a correlation of 1.00 (four out of four) between the four 15-minute quadrangles within which are located sites from which samples containing the most anomalous values of those elements were obtained. The quadrangle numbers are shown in parentheses below and also in Figure 2.

1. Zr and Hf (2, 3, 15, 23).
2. Sr, Sc, Na, Fe, Co, Ca, and Al (8, 16, 24, 32).
3. As and Sb (13, 14, 15, 21).
4. Ni and Mg (16, 24, 31, 32).
5. Yb, Sm, and La (23, 28, 29, 30).
6. Tb, Lu, and Dy (20, 28, 29, 30).

The following groups of elements have a correlation of 0.75 (three out of four) as explained above.

1. Zr and Eu (2, 3, 15).
2. Hf and Eu (2, 3, 15).
3. Mn and Cu (10, 11, 16).
4. Sn and Rb (20, 29, 30).
5. V and Sr, Sc, Na, Fe, Co, Ca, and Al (8, 16, 24).
6. W and As and Sb (14, 15, 21).
7. Ce and Th (4, 23, 29).

8. Ba, Ni, and Mg (16, 24, 32).

9. Ba and Sr, Sc, Na, Fe, Co, Ca, and Al (16, 24, 32).

10. Yb, Sm, and La versus Tb, Lu, and Dy (28, 29, 30).

11. U and Tb, Lu, and Dy (20, 28, 29).

12. K and Tb, Lu, and Dy (20, 28, 29).

13. Pb, Zn, and Be (13, 20, 29).

Most elements that occur in anomalous concentrations in stream-sediment samples have their provenance in Quaternary rhyolitic rocks. These include U, Th, seven rare earths, ore metals (Bi, Pb, Sb, Sn, W, and Zn), rare metals (Be, Cs, Li and Ta), and also K, Rb, As, and Cl. Those within Yellowstone National Park are associated chiefly with the Lava Creek and Huckleberry Ridge tuffs of the Yellowstone Group. In addition, 15 flows of the Central Plateau Member of the Plateau Rhyolite as well as the Mount Jackson and Lewis Creek rhyolites are also probable sources of anomalous metals in stream-sediment samples.

Stream-sediment samples containing anomalous amounts of major elemental constituents of andesite (Al, Ca, Fe, Mg, Na, and Ti) as well as Ba, Co, Ni, Sc, Sr, and V have a provenance in the andesitic rocks of the Absaroka Volcanic Supergroup of Eocene age along the eastern margin of the Ashton quadrangle. The chief source rocks are the Lamar River, Langford, Two Ocean and Wiggins Formations. Other probable contributors are the Wapiti and Mount Wallace Formations and the Trout Creek trachyandesite.

Most stream sediments containing anomalous amounts of Mn, Eu, Hf, and Zr have a provenance in Precambrian gneiss and schist. The Tanner manganese prospect (Mitchell et al., 1981) is upstream from one such anomalous-sample site.

For a few anomalous elements, the provenance is mixed. Cd and Cr seem to be equally associated with Tertiary andesite and Quaternary rhyolitic rocks. Some Eu, Hf, and Zr are also related to Quaternary rhyolite. Cu seems to be equally derived from Tertiary volcanics and Quaternary rhyolite while Nb has its probable provenance divided between Quaternary rhyolite and Quaternary basalt.

It is significant that erosion from other rock units in the Ashton quadrangle has not formed sediments containing appreciably anomalous values of any of the 45 elements in this study.

NURE stream-sediment samples originally were collected, analyzed, and the resultant data published to facilitate exploration for additional uranium resources in the United States. However, the interpretation of this array of multi-elemental analytical data may be far more important either directly in seeking new resources of many of the elements cited or indirectly as pathfinders to resources of other metals not readily analyzed in the NURE program.

Obviously, there is no intent to encourage mineral exploration in Yellowstone National Park. However, other uses of these geochemical data include the solution of purely scientific geologic problems related to the provenance of stream sediments within and adjoining the park. For example, the ultimate derivation of multicyclic sediments can be deduced. Also this is another tool for determining a more detailed Pleistocene geologic history of the park.

Acknowledgments

C. W. Myers encouraged the research pertaining to the interpretation of the Ashton geochemical data. A. C. Waters critically reviewed the manuscript.

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FIGURE CAPTIONS

Fig. 1. Location map of the Ashton 1:250,000 quadrangle, Idaho/Montana/Wyoming.

Fig. 2. Anomalous concentrations of elements in stream-sediment samples in the Ashton 1:250,000 quadrangle, Idaho/Montana/Wyoming.

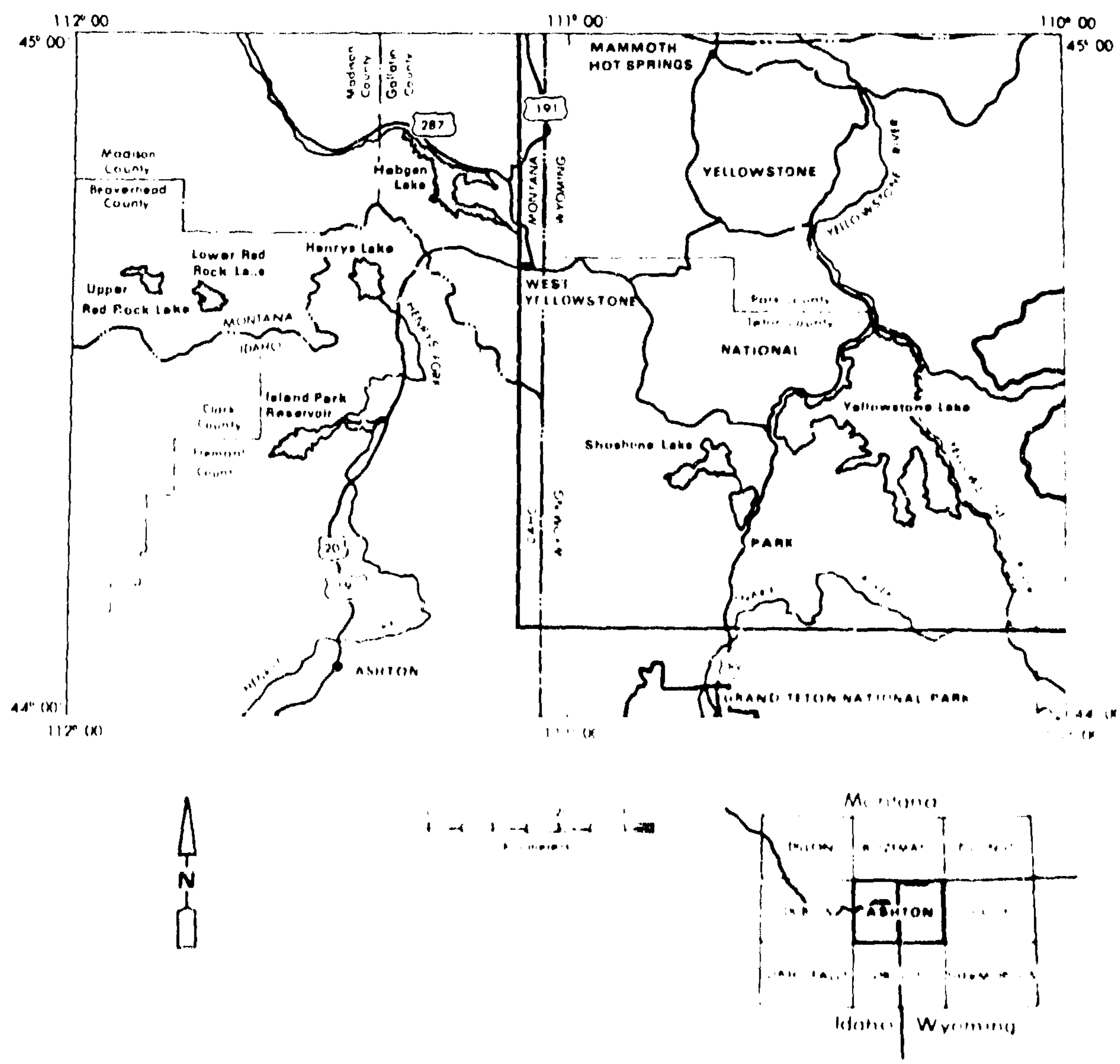
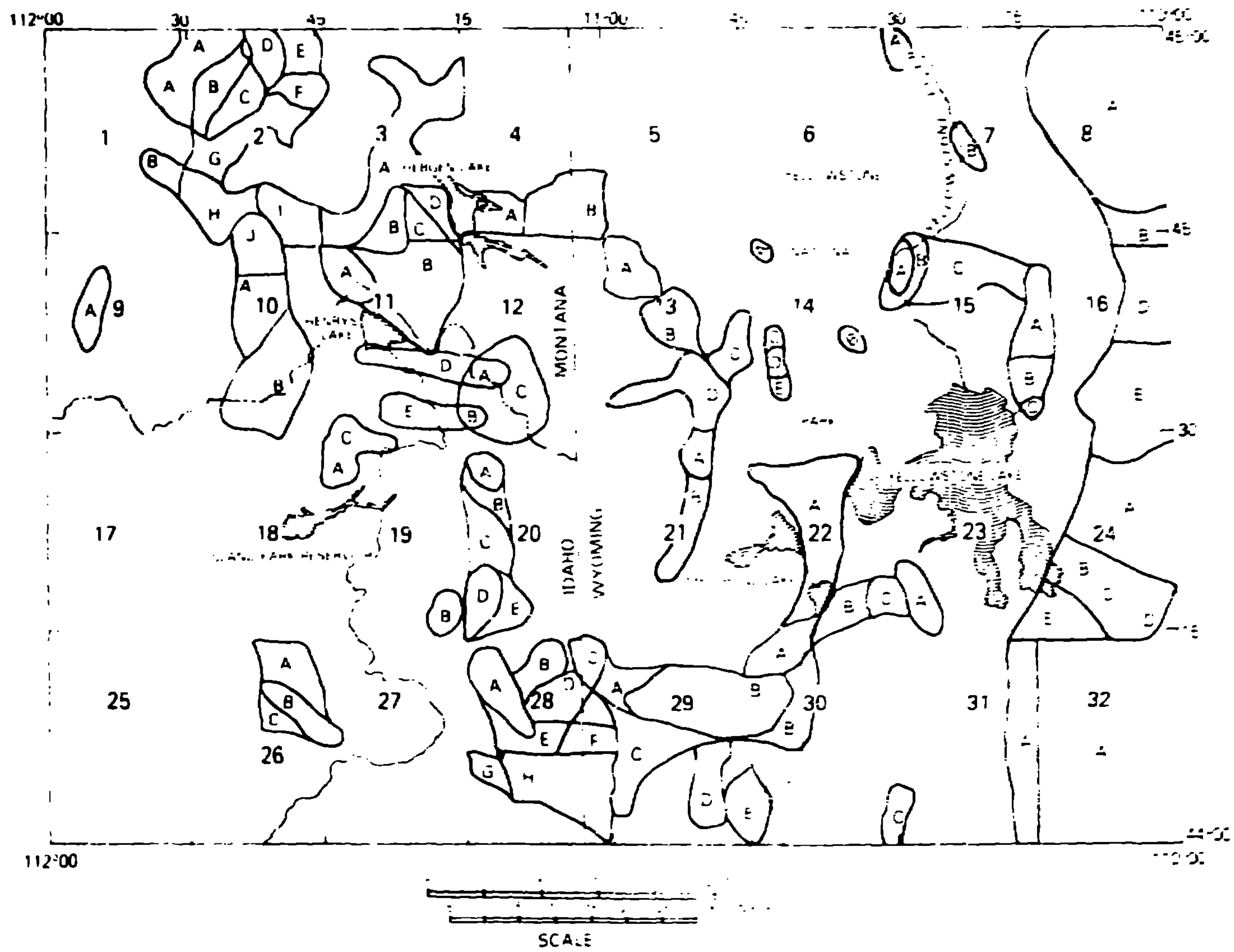


Fig. 1. Location map of the Ashton NTMS quadrangle, Idaho/Montana/Wyoming


112°00
30
45
15
111°00
30
45°00
1
2
3
4
5
6
7
8
9
10
11
12
14
15
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17
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21
22
23
24
25
26
27
28
29
30
31
32
HEBGEN LAKE
HENRYS LAKE
MONTANA
IDAHO
WYOMING
44°00
112°00
SCALE

APPENDIX

ASSOCIATION OF ANOMALOUS CONCENTRATIONS OF ELEMENTS IN STREAM SEDIMENT SAMPLES WITH GEOGRAPHIC AREAS AND LOCAL GEOLOGY, ORDERED BY QUADRANGLE

Quadrangle	Geologic Area	Elements	Geology
1	A. Horse Creek	Titanium	Upper Paleozoic strata (ss, ls, dol), fault parallel's Horse Creek.
	B. Elk River	Titanium	Upper Paleozoic strata (ss, ls, dol).
2	A. Granite Mountain-Bobcat Creek	Titanium	Tertiary basalt and other volcanics, undivided Precambrian rocks and upper Paleozoic strata (ss, ls, dol).
	B. Middle Horse Creek	Europium, hafnium, titanium, and zirconium	Undivided Precambrian rocks, Tertiary volcanics.
	C. Standard Creek-Tower Horse Creek	Titanium	Undivided Precambrian rocks, Tertiary volcanics.
	D. Moose Creek	Chromium and titanium	Quaternary terrace deposits and alluvium.
	E. Finger Mountain	Chromium	Precambrian gneiss, schist, and Quaternary terrace deposits.
	F. Squaw Creek	Chromium, europium, hafnium, titanium, and zirconium	Precambrian gneiss and schist and Quaternary glacial and terrace deposits.
	G. Freezeout Mountain-Papoose Creek	Europium, hafnium, and zirconium	Precambrian gneiss and schist, Tertiary volcanics, and Quaternary glacial and terrace deposits.
	H. Elk River-Tepee Creek	Europium, hafnium, titanium, and zirconium	Precambrian gneiss and schist, Tertiary volcanics.
	I. Cliff Lake	Europium, hafnium, and zirconium	Tertiary volcanics, Quaternary terrace deposits.
	J. Meridian Creek	Copper	Tertiary volcanics.
3	A. Horn Creek-Earthquake Lake-Beaver Creek	Europium, hafnium, and zirconium	[illegible] gneiss and schist, Mesozoic strata (ss, sts, [illegible]), [illegible] Paleozoic strata (ss, ls, dol), [illegible] and terrace deposits.
	B. Sheep Point	Europium, hafnium, manganese, and zirconium	Precambrian gneiss and schist, Cambrian limestone and [illegible]stone.
	C. Coffin Creek	Manganese	Precambrian gneiss and schist, Cambrian limestone and [illegible]stone.
	D. Watkins Creek	Bismuth, europium, hafnium, manganese, and zirconium	Precambrian gneiss and schist.
4	A. Rainbow Point-Grayling Creek	Bismuth	Quaternary rhyolite (Huckleberry Ridge Tuff), Precambrian gneiss and schist, Tertiary basalt (Mt. [illegible] Formation), Quaternary sediments.

APPENDIX (Cont.)

Quadrangle	Geologic Area	Elements	Geology
	B. Gneiss Creek	Bismuth, cerium, lithium, and thorium	Quaternary rhyolite (Huckleberry Ridge and Lava Creek tuffs), Tertiary conglomerate (Sepulcher Formation), Precambrian gneiss and schist, Quaternary alluvium and glacial deposits.
5	None		
6	None		
7	A. Hellroaring Creek	Copper	[illegible] rhyodacite and andesite (Sepulcher Formation), Precambrian gneiss and schist, Quaternary rhyolite ([illegible] Ridge Tuff), Quaternary sediments.
	B. Agate Creek	Copper	Quaternary rhyolite (Lava Creek Tuff), Tertiary andesite ([illegible] Formation), Quaternary basalt (Junction Butte [illegible]), Quaternary sediments.
8	A. Soda Butte Creek-Lache Creek	Aluminum, barium, calcium, cobalt, iron, magnesium, scandium, strontium, and vanadium	[illegible] Formation), Tertiary andesite [illegible] basalt (Wapiti and Mount Wallace Formations), Tertiary [illegible] (Trout Creek trachyandesite), Paleozoic [illegible], Quaternary rhyolite (Lava Creek Tuff), Quaternary sediments.
	B. Chaffee Creek	Aluminum, barium, calcium, cobalt, iron, magnesium, nickel, scandium, strontium, and vanadium	Tertiary andesite and basalt (Wapiti Formation), Tertiary [illegible] Formation), Quaternary rhyolite (Lava Creek Tuff), Quaternary sediments.
9	A. Red Rock River	Chlorine	[illegible], Tertiary [illegible]
10	A. Elk Mountain-Hidden Lake	Copper	Tertiary volcanics, Precambrian gneiss and schist, Precambrian dolomite, Pliocene-Pleistocene rhyolite, [illegible] basalt, Quaternary fan deposits and alluvium.
	B. Nemesis Mountain	Manganese (includes Tanner Mtn. prospect (Mitchell et al., 1981))	[illegible] Pleistocene rhyolite, Tertiary volcanics, [illegible] gneiss and schist, Precambrian dolomite, [illegible] quartzite, Paleozoic strata (ss, ls, dol), [illegible], Triassic strata (ss, sh).
11	A. Reynolds Pass	Manganese and zinc	[illegible] gneiss and schist, Precambrian dolomite, [illegible] quartzite, Quaternary fan deposits and alluvium, [illegible]
	B. Targhee Peak	Manganese	[illegible]
	C. Yale Creek	Chromium and copper	[illegible], Tertiary volcanics, Quaternary basalt, [illegible] alluvium.

APPENDIX (cont.)

Quadrangle	Geologic Area	Elements	Geology
	D. Jesse Creek	Chromium	Quaternary rhyolite, Tertiary volcanics, Quaternary sediments.
	E. Henrys Fork north of Macks Inn	Niobium	Quaternary rhyolite, Quaternary alluvium.
12	A. Reas Pass Siding	Chromium, rubidium, and uranium	Quaternary rhyolite.
	B. Thirsty Creek	Niobium and rubidium	Quaternary rhyolite, Quaternary alluvium and fan deposits.
	C. Reas Pass	Rubidium and uranium	Quaternary rhyolite, Quaternary alluvium and fan deposits.
13	A. Cougar Creek	Lithium and lutetium	Quaternary rhyolite (Lava Creek Tuff), Quaternary basalt (Madison River Basalt), Quaternary fan deposits.
	B. Madison Junction	Bismuth	Quaternary rhyolite (Lava Creek Tuff, west Yellowstone and [illegible] Creek flows, Mount Jackson rhyolite), Quaternary [illegible].
	C. Nez Perce Creek	Bismuth, lead, and zinc	Quaternary rhyolite (Nez Perce Creek flow), Quaternary [illegible].
	D. Lower Geyser Basin-Sentinel Creek	Antimony, beryllium, bismuth, chlorine, cesium, and lithium	Quaternary rhyolite (west Yellowstone and Elephant Back flows, Upper Basin Member), Quaternary hot spring deposits, [illegible] sediments.
14	A. West of Norris Junction	Antimony, arsenic, and tungsten	[illegible] (Lava Creek Tuff), Quaternary hot-spring [illegible], Quaternary sediments.
	B. Alum Creek	Antimony	[illegible] rhyolite (Hayden Valley flow), Quaternary [illegible].
	C. Maple Creek	Beryllium	Quaternary rhyolite (Nez Perce Creek and Mary Lakes flows), Quaternary sediments.
	D. Nez Perce Creek	Antimony, arsenic, beryllium, and tungsten	Quaternary rhyolite (Mary Lake and Elephant Back flows), Quaternary sediments.
	E. Juniper Creek	Beryllium	Quaternary rhyolite (Elephant Back flow), Quaternary [illegible].
15	A. Artist Point	Antimony, arsenic, barium, cadmium, europium, hafnium, tungsten, and zirconium	Quaternary rhyolite (Upper Basin Member), Quaternary sediments.
	B. Artist Point (outer ring)	Barium, europium, hafnium, zirconium	Quaternary rhyolite (Upper Basin Member, Hayden Valley and Solfatara Plateau flows), Quaternary sediments.
	C. Sour Creek-upper Broad Creek	Europium, hafnium, zirconium	Quaternary rhyolite (Upper Basin Member, Hayden Valley and Solfatara Plateau flows), Quaternary sediments.

APPENDIX

ASSOCIATION OF ANOMALOUS CONCENTRATIONS OF ELEMENTS IN STREAM-SEDIMENT SAMPLES WITH [illegible] AREAS AND LOCAL GEOLOGY, ORDERED BY QUADRANGLE

Quadrangle	Geologic Area	Elements	Geology
1b	A. Upper Pelican Creek	Aluminum, barium, europium, hafnium, and zirconium	[illegible] rhyolite (Lava Creek Tuff), Tertiary andesite [illegible] Formation), Tertiary trachyandesite (Trout Creek [illegible]), and Quaternary sediments.
	B. Sedge Creek	Aluminum and barium	[illegible] rhyolite (Lava Creek Tuff), Quaternary hot-spring deposits, Quaternary alluvium.
	C. Tributaries to Turbid Lake	Silver	[illegible] rhyolite (Lava Creek Tuff), Quaternary hot-spring [illegible] Quaternary sediments. The northeasterly [illegible] to northwest.
	D. Cold Creek	Aluminum, barium, calcium, cobalt, iron, magnesium, scandium, sodium, strontium, titanium, and vanadium	[illegible] andesite and basalt (Wapiti and Mount Wallace [illegible]), Tertiary trachyandesite (Trout Creek [illegible]), Tertiary andesite (Langford Formation), [illegible] rhyolite (Lava Creek Tuff), Quaternary sediments.
	E. Jones Creek	Aluminum, barium, calcium, cobalt, copper, iron, magnesium, manganese, nickel, scandium, sodium, strontium, titanium, and vanadium.	[illegible] andesite (Langford Formation), Quaternary [illegible].
1	None		
1[illegible]	None		
1[illegible]	A. Hotel Creek	Chromium and copper	Quaternary rhyolite, Quaternary alluvium.
	B. Pineview Siding	Niobium	Quaternary basalt, Quaternary rhyolite. Northeasterly [illegible].
2D	A. Moose Creek	Beryllium, lutetium, potassium, terbium, and uranium	Quaternary rhyolite, Quaternary alluvium.
	B. Chick Creek	Lutetium, potassium, terbium, and uranium	Quaternary rhyolite.
	C. Split Creek	Dysprosium, lead, lutetium, potassium, rubidium, uranium, and zinc	Quaternary rhyolite.
	D. Partridge Creek	Beryllium, dysprosium, lutetium, potassium, rubidium, and terbium	Quaternary rhyolite.
	E. South Fork Partridge Creek	Lut[illegible]m, potassium, and terbium	Quaternary rhyolite.

APPENDIX (cont.)

Quadrangle	Geologic Area	Elements	Geology
21	A. Upper Geyser Basin	Antimony, beryllium, cesium, chlorine, and tantalum	Quaternary rhyolite (Mallard Lake Member, West Yellowstone flow, Upper Basin Member), Quaternary hot-spring deposits, Quaternary alluvium.
	B. Firehole River	Antimony, arsenic, chlorine, cesium, and tungsten	Quaternary rhyolite (Summit Lake, Grants Pass, and Spring Creek flows), Quaternary sediments.
22	A. Lewis Lake-Chickadee Lake	Lead and potassium	Quaternary rhyolite (Shoshone Lake Tuff Member, Aster Creek, Dry Creek, Elephant Back, and Pitchstone Plateau flows), Quaternary sediments.
	B. Aster Creek	Lithium	Quaternary rhyolite (Huckleberry Ridge Tuff, Aster Creek flow), Quaternary sediments.
	C. Heart Lake Geyser Basin	Cesium and lithium	Quaternary rhyolite (Huckleberry Ridge Tuff, Aster Creek flow), Quaternary hot-spring deposits, Quaternary sediments.
23	A. Beaver Creek	Bismuth, cerium, hafnium, lanthanum, samarium, thorium, ytterbium, and zirconium	Quaternary rhyolite (Lava Creek Tuff, Mount Jackson Rhyolite, Aster Creek flow), Quaternary sediments.
24	A. Mount Langford	Aluminum, barium, calcium, cobalt, iron, magnesium, nickel, scandium, sodium, strontium, and vanadium	Tertiary andesite (Langford Formation, Two Ocean Formation), Tertiary trachyandesite (Trout Creek Trachyandesite), Quaternary sediments.
	B. Beaverdam Creek	Aluminum, barium, cadmium, calcium, cobalt, iron, magnesium, nickel, scandium, sodium, strontium, and vanadium	Tertiary andesite (Langford Formation, Two Ocean Formation), Tertiary trachyandesite (Trout Creek Trachyandesite), Quaternary sediments.
	C. Trappers Creek	Aluminum, barium, cadmium, calcium, cobalt, iron, magnesium, nickel, scandium, sodium, strontium, titanium, and vanadium	Tertiary andesite (Langford Formation, Two Ocean Formation), Quaternary sediments.
	D. Mountain Creek	Aluminum, barium, cadmium, calcium, [illegible], cobalt, iron, magnesium, nickel, scandium, sodium, strontium, titanium, and vanadium	Tertiary andesite (Langford Formation, Two Ocean Formation), Quaternary sediments.
	E. Trail Creek	Aluminum, barium, cadmium, calcium, cobalt, iron, magnesium, nickel, scandium, sodium, strontium, and vanadium	Andesite (Quaternary rhyolite) (Langford Formation), Quaternary sediments.
25	None		
26	A. Blue Creek	Bismuth	Quaternary rhyolite, Quaternary alluvium.
	B. Rattlesnake Creek	Bismuth and chlorine	Quaternary rhyolite, Quaternary alluvium.
	C. Spring Creek	Bismuth	Quaternary rhyolite, Quaternary basalt, Quaternary alluvium.

Quadrangle	Geologic Area	Elements	Geology
27	None		
28	A. Moose Creek-Snow Creek	Dysprosium, lanthanum, lithium, lutetium, niobium, potassium, samarium, tantalum, thorium, and uranium	Quaternary rhyolite, Quaternary basalt.
	B. Upper Snow Creek	Dysprosium, lanthanum, lithium, lutetium, potassium, tantalum, thorium, and uranium	Quaternary rhyolite (Buffalo Lake flow), Quaternary glacial deposits.
	C. Lake Wyodaho	Berryllium, dysprosium, europium, lanthanum, lithium, lutetium, samarium, tantalum, thorium, tin, uranium, and ytterbium	Quaternary rhyolite (Summit Lake flow), Quaternary basalt (Falls River Basalt), Quaternary glacial deposits, Quaternary sediments.
	D. Horseshoe Lake	Lithium, potassium, and uranium	Quaternary rhyolite (Lava Creek Tuff), Quaternary basalt (Falls River Basalt), Quaternary glacial deposits, Quaternary sediments.
	E. Upper Rock Creek	Lithium, niobium, potassium, and uranium	Quaternary basalt (Falls River Basalt), Quaternary rhyolite.
	F. ID-WY-YNP common point	Niobium	Quaternary basalt (Falls River Basalt), Quaternary rhyolite (Lava Creek Tuff), Quaternary sediments.
	G. Porcupine Creek	Titanium	[illegible] basalt, Quaternary rhyolite, Quaternary glacial [illegible], Quaternary alluvium.
	H. Falls River Ridge	Lithium and titanium	[illegible], Quaternary basalt, Quaternary [illegible]
	I. Boone Creek	Titanium	[illegible] basalt, Quaternary rhyolite, Quaternary glacial [illegible], Quaternary alluvium.
29	A. Lower Bechler River	Beryllium, dysprosium, europium, lanthanum, lutetium, samarium, terbium, tin, and ytterbium	Quaternary rhyolite (Pitchstone Plateau flow), Quaternary [illegible] (Falls River Basalt), Quaternary sediments.
	B. Mountain Ash Creek-Beula Lake	Beryllium, cerium, dysprosium, europium, lanthanum, lead, lutetium, potassium, rubidium, samarium, tantalum, terbium, thorium, tin, uranium, and ytterbium	Quaternary rhyolite [illegible]tchstone Plateau flow, Lewis Canyon rhyolite, Lava Creek Tuff, Huckleberry Ridge Tuff,, Tertiary dacite, Quaternary basalt (Falls River Basalt), Triassic strata (sts, sh), Tertiary andesite (Absaroka Volcanic Supergroup), Lower Paleozoic strata (ls, dol, sh), Quaternary sediments. Numerous northerly faults in eastern part.
	C. Loon Lake	Cerium, dysprosium, europium, lanthanum, lutetium, potassium, rubidium, samarium, terbium, and thorium	Quaternary rhyolite (Huckleberry Ridge Tuff, Lava Creek Tuff), Quaternary basalt (Falls River Basalt), Tertiary [illegible], Upper Paleozoic strata (ss, ls, dol), Quaternary [illegible] deposits, Quaternary alluvium.

APPENDIX (cont.)

Quadrangle	Geologic Area	Elements	Geology
	D. Survey Peak	Europium	Quaternary rhyolite, Paleozoic strata (ls, dol, ss, sh), Tertiary basalt, undivided Precambrian rocks, Triassic shale, Quaternary glacial deposits.
	E. Lower Berry Creek	Chromium	Mesozoic strata (sh, ss), Quaternary rhyolite, Upper Paleozoic strata (ls, ss), Quaternary glacial deposits, Quaternary alluvium.
30	A. Upper Lewis River	Cesium, dysprosium, lanthanum, lead, lithium, lutetium, samarium, tantalum, and terbium	Quaternary rhyolite (Pitchstone Plateau flow).
	B. Lower Lewis River	Cerium, dysprosium, lanthanum, lithium, lutetium, samarium, and uranium	Quaternary rhyolite (Lava Creek Tuff, Lewis Canyon Rhyolite), Carboniferous strata (ls, ss), Triassic strata (sls, sh, ss), Quaternary sediments.
	C. Bobcat Ridge (partly Quadrangle #31)	Gold	Cretaceous claystones, Paleocene strata, Quaternary in rhyolite.
31	A. Eastern border	Same as all of Quadrangle #32.	
32	A. Entire quadrangle	Aluminum, barium, calcium, cobalt, iron, magnesium, nickel, scandium, sodium, and strontium	Tertiary andesite (Wiggins Formation, Two Ocean Formation), Paleozoic strata (ls, dol, ss), Quaternary basalt (Basalt of Mariposa Lake), Quaternary sediments, Quaternary glacial deposits.